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# Near-Infrared Reflectance Instrument Analysis of Grain Constituents: A Cost Study

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U.S. Department of Agriculture

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Costs of using near-infrared reflectance (NIR) instruments for determining protein and moisture content of grains and their products are synthesized for five levels of operation: 5, 10, 20, 40, and 80 samples per shift. Variable costs are substantially greater than fixed costs, with operator wages the major contributing factor. Cost comparisons between NIR per-sample estimates and charges for Kjeldahl sample analysis by commercial laboratories indicate lower NIR costs at 20, 40, and 80 samples per shift. If economic value were placed on advantageous factors of the NIR method over the Kjeldahl method, cost comparison would be even more favorable for the NIR method.

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# SUMMARY

Cost estimates indicate that using near-infrared reflectance (NIR) instruments to measure protein and moisture content in grains and their products is a practical method of analysis. Also, the NIR method generates rapid analysis (45 to 120 seconds, including sample preparation, depending on the instrument model and operations performed) which allows its use in a multitude of grain industry operations previously denied protein monitoring applications by slower methods of determination.

Per-sample operating costs of the NIR method are estimated for five levels of operation: 5, 10, 20, 40, and 80 samples per 8-hour shift. These are further divided into two categories: low-cost estimates for when the NIR instrument is installed in a controlled-environment laboratory, and high-cost estimates which require additional expenditures to provide minimum instrument operating conditions in other locations.

Comparisons between NIR per-sample cost estimates and charges for Kjeldahl sample analysis by commercial laboratories indicate lower NIR costs in low-cost estimates with 10 samples per shift, and for both low- and high-cost estimates at 20, 40, and 80 samples per shift. In addition, NIR users report other advantages over the Kjeldahl method of analysis: space requirements are smaller, installation and maintenance are less expensive, there are fewer safety hazards, and operator training is less time consuming and less rigorous. If economic value were placed on these advantageous factors of the NIR method, the cost comparison would be even more favorable over the Kjeldahl method.

Investment requirements for equipment and installation range from $16,460 to $17,720. Operating costs decrease considerably as the number of samples analyzed increases. Fixed costs at all sample levels are assumed to be constant; thus, they decline in percentage of total cost as the number of samples analyzed per shift increases. Variable costs increase primarily because of increased labor costs associated with higher numbers of samples analyzed.

# NEAR-INFRARED REFLECTANCE INSTRUMENT ANALYSIS OF GRAIN CONSTITUENTS: A Cost Study

*Floyd F. Niernberger**

## INTRODUCTION

Grain quality is determined by constituent value (protein, oil, starch, etc.) which must be properly identified so only grain with similar constituent values will be commingled. This means a grain's content must be determined at the beginning of handling and storage so it may be set aside for later use.

Country, terminal, and port elevators have developed unloading techniques and equipment which move grain from receiving vehicles to storage bins as quickly as 2 to 5 minutes. In order for a constituent analysis method to be practical, it must determine grain content within these time limits. 1/

Cost estimates indicate that an economically feasible answer may be near-infrared reflectance (NIR) instruments, which can analyze samples in 45 to 120 seconds (including sample preparation), depending on the instrument model and operations performed.

This report gives estimates of investment and operating costs of using NIR instruments to determine protein and moisture content in grains and their products. Annual cost schedules of per-sample analysis are presented for five levels of operation. Procedures to convert per-sample costs to per-bushel costs also are provided. These estimated costs of NIR instrument analysis are compared with sample-testing charges of commercial laboratories.

The information and cost estimates contained in this report should provide useful guidelines for anyone in the grain industry considering investment in an NIR instrument. Grain producers, handlers, merchandisers, and laboratories concerned with grain content testing can use this information to plan improvement of their specific operations and their profit.

The standard laboratory method for estimating protein in grains and their products is the Kjeldahl test (1), which is based on nitrogen content and has been widely accepted since introduction of the original procedure in 1883. 2/ In 1975, Pomeranz and Moore reviewed the method and described its usefulness in grain protein evaluation (3). Other types of chemical tests for protein and modifications of the official

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1/ Grain holding bins may be installed in the unloading system to allow time for slower analysis methods, but costs escalate rapidly as grain volume increases.

2/ Underscored numbers in parentheses refer to references listed at the end of this report.

Kjeldahl method also are used by the grain trade. These were developed primarily to meet a need for decreasing the time required to perform the standard Kjeldahl test.

The standard method for estimating moisture has been the single-stage, air oven moisture test (2). Other methods also are used in commercial grain trade and by the Federal Grain Inspection Service (FGIS).

Research investigations into procedures and techniques for developing NIR spectrophotometry to determine the quality constituents of agricultural products have been carried out since the sixties. A review of these investigations and a description of NIR instruments used for determination of protein, oil, and moisture in grains, oilseeds, and feedstuffs have been reported by Watson (12).

The NIR technique for protein and moisture determination has gained steady acceptance by the grain industry since the first commercial instruments were introduced in early 1971 (3). The Federal Grain Inspection Service began NIR use on May 1, 1978, for official protein testing on hard red winter and hard red spring wheats upon request (11). In implementing official protein testing on U.S. grain exports, approved NIR equipment will be used exclusively for original, supervision, and appeal testing. For domestically marketed hard red winter and hard red spring wheats, official agencies may use NIR equipment or any other wheat protein device approved by the FGIS administrator.

The NIR method's capacity for rapid protein and moisture content analysis makes it useful to a multitude of grain industry operations heretofore denied protein content monitoring by slower methods. Grain firms normally operate processing facilities through continuous commodity flow procedures rather than individual batch operations. Constituent analyses of continuous process flow grains require fast testing for proper quality control, particularly where the grain products are to be blended (together) with other higher valued ingredients into consumer products.

In addition to the rapid testing capability, other advantages of the NIR over the Kjeldahl method have been reported by manufacturers and users (4, 10). When the NIR instrument is chosen over the Kjeldahl unit, space requirements are smaller, installation and maintenance are less expensive, there are fewer safety hazards, and operator training is less time consuming and less rigorous.

Estimates of costs incurred in NIR instrument use to test grain for protein and moisture have been reported by Williams (13). Costs were prepared using data from the Canadian Grain Commission's main inspection laboratory in Winnipeg and are applicable to Canada. Costs of operating this highly automated NIR system averaged $0.74 per sample on 135,000 samples analyzed between June and December 1975.

## METHODOLOGY

The economic-engineering approach is used to develop cost estimates for five usage levels of NIR instruments in determining protein and moisture content of grains and their products. 3/ Low- and high-cost estimates for each level of operation also are figured. Low-cost estimates apply when the NIR instrument and associated equipment are

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3/ This approach required determining input needs (equipment, space, and labor) and output results (samples performed per time period) for development of cost relationships at several levels of operation. Costs determined in this manner are termed synthetic; they do not reflect costs actually experienced in any firm's or individual's operations, but represent a synthesis of operations observed in a number of cases. The costs are contingent upon assumptions and specifications used in setting up the study.

installed in a controlled-environment, quality-assurance laboratory. These estimates could be considered minimum costs, because such a laboratory would have been designed to provide operating conditions well-suited for sample preparation, grinding, and NIR instrument operation. High-cost estimates require additional expenditures to provide minimum NIR instrument operating conditions in nonlaboratory locations. These high-cost estimates provide for stabilizing the voltage supply to the instrument, controlling dust and noise in the sample preparation and grinding area, and locating the NIR instrument within an area of generally constant room temperature to avoid temperature extremes. The high-cost situation would apply to installation of NIR instruments in elevator grain unloading areas, plant processing locations, and grain and product loadout facilities already existing where some protection is needed from surrounding conditions and equipment operations.

The categories used for cost analyses in this study are based on an average daily number of samples analyzed during a single 8-hour shift by one operator. Workloads and operator performance may fluctuate greatly throughout the year; consequently, annual sample capacity for each category also should be considered. The annual sample capacity is based on 260 operating days per year. This number of operating days was selected because it is felt that Saturday and Sunday operation of grain industry firms at peak handling periods probably equal weekday shutdowns due to holidays during the year.

For this study, it is assumed that a single operator can analyze an average of 80 samples of grains and their products for protein and moisture content during an 8-hour shift, with a yearly average of 20,800. This assumption takes into account that several kinds of commodities would be analyzed and that samples can be analyzed at a much greater rate for rush needs.4/ Furthermore, the operator would have the usual rest periods and other nonoperating times experienced in actual operation. The time allowed for analysis includes grinding, loading, and removing samples, recording data on necessary forms, cleaning up, and disposing of ground samples. General maintenance of the equipment and premises also is included in the sample-rate estimate.

The rate of samples analyzed per shift in this study does not include labor and time in obtaining the sample grain or product to be tested. Estimates of labor and time for sampling different containers, vehicles, storage facilities, and processes are believed too variable to be meaningful. Thus, it is assumed that samples of commodities to be analyzed are located within a short distance of the analysis area and are easily accessible to the operator. This assumption would be logical for most laboratory operations; however, users at isolated locations or processes should be cautioned that if the operator also must take the sample physically from the commodity or product to be analyzed, a lower rate than 80 samples per shift should be expected.

Using this maximum level of operation as a basis, additional levels of sample analyses per shift are estimated to provide a range of situations for potential user examination. Thus, cost data are estimated for 80, 40, 20, 10, and 5 samples per shift, all applicable to a 260-day annual operation. 5/

Managers of grain firms would have available from past records expenditures and numbers of analyses made annually for their particular operation. They could compare

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4/ It is generally accepted that NIR instruments presently being marketed can meet criteria consisting of total measurement time for protein and moisture per sample of hard wheats, less grinding, but including sample cup packing, of less than 90 seconds as specified by FGIS in ST NOTICE 15, December 30, 1977.

5/ Appendix A describes a procedure to develop cost data on a per-bushel basis for those in the grain industry preferring to make a cost analysis on a bushel rather than a sample basis. Appendix table 1 provides a limited range of annual throughput quantities applicable to the five usage levels.

the estimated NIR analysis per-sample cost at the closest use level to their own data and determine cost differences. Managers who feel that it would be advantageous to their operation to perform many more analyses could determine estimated per-sample costs at higher sample-per-shift levels.

Practices applicable to an individual firm may not be covered by this study, since it is designed to provide general information on a limited number of costs. In such instances, equipment manufacturers and engineering firms may be consulted to provide estimates for a specific operation.

## COSTS

Costs are classified as investment and operating, with the latter further classified as fixed and variable. Investment and operating costs are representative of the Kansas City, Mo., area as of January 1, 1978. Costs for other locations may vary from this reference site and should be determined for each application. Fixed costs include depreciation, interest on investment, space assessment, training expenses, taxes, and insurance. Variable costs include operator wages, maintenance, repairs, calibration tests, and utilities.

### Investment Costs

Initial investment costs include the NIR instrument itself, associated equipment, and installation costs. Equipment costs vary by manufacturer, model, and recommended accessories (see appendix B). Installation costs vary with the facility and the location within the facility where the equipment is installed. A major factor influencing installation costs is whether a controlled-environment for the NIR equipment already exists in the proposed location. Installation in quality-assurance laboratories may require no more than clearing an existing table or setting up an instrument bench and plugging the sample grinder and NIR instrument into electrical receptacles. Nonlaboratory locations can necessitate installing electrical circuits and voltage regulator; closing in the analysis area; and providing noise, dust, and temperature control equipment (in general, providing satisfactory equipment and operator conditions for accurate sample preparation and analysis). Table 1 presents equipment and installation costs for these two situations.

Equipment costs were furnished by the manufacturers. Installation costs were obtained from both manufacturers and firms using NIR instruments.

### Operating Costs

Operating cost estimates are shown in table 2. They do not include costs of obtaining the grain or commodity sample to be tested, or costs of recording data, preparing forms, and keeping information transcribed from the NIR instrument operator's daily log sheets. High-cost estimates include the higher cost of accessories and other equipment listed in table 1.

#### Fixed Costs

Depreciation on the initial investment in equipment, including installation, is spread over the estimated productive life of the equipment and makes up the major portion of fixed costs. Other costs that do not vary with output are interest on investment, space assessment, training expenses, taxes, and insurance.

Table 1--Equipment and installation costs of near-infrared reflectance instrument, grinder, and associated accessories, 1978

| Cost item | Equipment costs 1/ |  | Installation, electrical, and setup costs 1/ |  | Total costs 1/ |  |
|---|---|---|---|---|---|---|
|  | Low | High | Low | High | Low | High |
|  |  |  | Dollars |  |  |  |
| Direct: |  |  |  |  |  |  |
| NIR instrument 2/ | 14,500 | 14,500 | 25 | 100 | 14,525 | 14,600 |
| Sample grinder | 745 | 745 | 25 | 100 | 770 | 845 |
| Accessories | 55 | 155 | -- | -- | 55 | 155 |
| Tax and freight | 790 | 795 | -- | -- | 790 | 795 |
| Total direct | 16,090 | 16,195 | 50 | 200 | 16,140 | 16,395 |
| Indirect: |  |  |  |  |  |  |
| Instrument bench and chair | 175 | 175 | 10 | 50 | 185 | 225 |
| Work table and chair | 125 | 125 | 10 | 50 | 135 | 175 |
| Total indirect | 300 | 300 | 20 | 100 | 320 | 400 |
| Other: |  |  |  |  |  |  |
| Air conditioner | -- | 300 | -- | 75 | -- | 375 |
| Room heater | -- | 100 | -- | 25 | -- | 125 |
| Hood and exhaust fan | -- | 250 | -- | 75 | -- | 325 |
| Accessories | -- | 100 | -- | -- | -- | 100 |
| Total other | -- | 750 | -- | 175 | -- | 925 |
| Total | 16,390 | 17,245 | 70 | 475 | 16,460 | 17,720 |

-- = not applicable.

1/ Low figure is minimum cost estimate where the NIR instrument is installed in controlled-environment laboratory. High figure is cost estimate for minimum instrument operating conditions in other locations.

2/ Average cost of three instruments listed in appendix B table 1, F.O.B. factory.

Table 2--Estimated annual operating costs of NIR instruments for five levels of protein and moisture determinations, 1978 1/

| Cost item | Cost by number of samples analyzed per 8-hour shift 2/ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | | 10 | | 20 | | 40 | | 80 | |
| | Low | High | Low | High | Low | High | Low | High | Low | High |
| | Dollars | | | | | | | | | |
| Fixed: | | | | | | | | | | |
| Depreciation | 3,292 | 3,544 | 3,292 | 3,544 | 3,292 | 3,544 | 3,292 | 3,544 | 3,292 | 3,544 |
| Interest on investment | 741 | 797 | 741 | 797 | 741 | 797 | 741 | 797 | 741 | 797 |
| Space assessment | 120 | 300 | 120 | 300 | 120 | 300 | 120 | 300 | 120 | 300 |
| Training expense | 126 | 189 | 126 | 189 | 126 | 189 | 126 | 189 | 126 | 189 |
| Taxes and insurance | 75 | 80 | 75 | 80 | 75 | 80 | 75 | 80 | 75 | 80 |
| Total fixed | 4,354 | 4,910 | 4,354 | 4,910 | 4,354 | 4,910 | 4,354 | 4,910 | 4,354 | 4,910 |
| Variable: | | | | | | | | | | |
| Operator wages 3/ | 3,640 | 3,850 | 3,640 | 3,850 | 7,280 | 7,700 | 10,920 | 11,550 | 14,560 | 15,400 |
| Maintenance and repair | 200 | 875 | 220 | 875 | 250 | 875 | 290 | 875 | 340 | 875 |
| Calibration tests | 100 | 150 | 150 | 300 | 250 | 600 | 400 | 1,200 | 600 | 2,400 |
| Utilities | 85 | 500 | 87 | 502 | 90 | 505 | 95 | 510 | 105 | 520 |
| Total variable | 4,025 | 5,375 | 4,097 | 5,527 | 7,870 | 9,680 | 11,705 | 14,135 | 15,605 | 19,195 |
| Total | 8,379 | 10,285 | 8,451 | 10,437 | 12,224 | 14,590 | 16,059 | 19,045 | 19,959 | 24,105 |
| Per-sample cost | 6.44 | 7.91 | 3.25 | 4.01 | 2.35 | 2.80 | 1.54 | 1.83 | .96 | 1.16 |

1/ Annual capacity based on 260 operating days. Five samples per day equal 1,300 samples annually; 10 samples per day, 2,600; 20 samples per day, 5,200; 40 samples per day, 10,400; and 80 samples per day, 20,800.

2/ Low figure is minimum cost estimate where the NIR instrument is installed in controlled-environment laboratory. High figure is cost estimate for minimum instrument operating conditions in other locations.

3/ See operator wages section in text for explanation of wage difference in low- and high-cost estimates.

Depreciation.--Equipment costs, including installation and electrical, are depreciated at an annual rate of 20 percent over a 5-year period. 6/ The service life of NIR instruments is difficult to estimate, because of the rapid technological advances since their commercial introduction to the grain industry in 1971, and because the relatively recent introduction precludes sufficient life expectancy information.

Interest on investment.--Interest on investment is calculated at 9 percent on half the equipment cost, including installation and electrical expense.

Space assessment.--A space estimate of 60 square feet is needed for satisfactory operation of the analysis equipment.

It is assumed that installation would be made in an existing facility. Charges suggested by a grain industry appraisal firm are $2 per square foot for the low-cost estimate, and $5 for the high-cost estimate. The suggested annual space charge for a facility under construction is $160 to $170 per $1,000 of building expense.

Training expense.--Several types of training programs are offered by NIR instrument manufacturers. It is assumed that as a minimum for the low-cost estimate, two operators would require training over the 5-year life of the instrument. The high-cost estimate includes one additional operator. Salary and local travel expenses within a 150-mile radius of the facility are included for each operator. It is further assumed that on-the-job training of part-time or extra operators could be done by an operator completing the NIR manufacturer's training program.

Taxes and insurance.--Taxes are calculated at 1 percent of assessed value. Assessed value for the Kansas City location is estimated at 35 percent of total cost. Insurance is estimated at 10 mills per $1 investment (.1 percent on 100 percent of the replacement cost).

## Variable Costs

Variable costs in this estimate include such items as operator wages, maintenance and repairs, calibration tests, and utilities that are a function of the number of samples analyzed. Wages paid to operators make up a large portion of variable costs and a major portion of total costs.

Operator wages.--The operator wage rate is based on a total wage of $7 per hour ($5.80 for wages plus 20 percent for fringe benefits) for semiskilled laboratory personnel in Kansas City. Local wage rates may be higher or lower for a particular firm. It is assumed that 80 samples per day require one operator for the 8-hour shift. The annual wage is based on 260 days' operation, and the assumption is made that the operator would need replacement for vacation or sickness for 15 days. The low-cost estimate assumes the firm will be able to replace the operator during the 15 days with diversion of personnel from other jobs at no additional labor charge. The high-cost estimate includes replacement personnel wages for the additional 15 days. It also is assumed that at the other four testing levels the operator who is not busy full time with NIR testing would be able to perform other work, thus, reducing labor charges directly attributable to NIR instrument operation. However, levels of operation below 80 samples per shift probably result in labor inefficiency in actual industry practice. According to NIR manufacturers and several NIR instrument users, 40 samples per shift should require one operator an average of 6 hours. The 20-, 10-, and 5-samples per shift operations would necessitate labor use of 4, 2, and 2 hours, respectively. The minimum labor selection of 2 hours of operation time after sample workloads decline past 10

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6/ Appendix C contains cost information on the effects of increasing the depreciation period beyond the 5-year assumption.

samples per shift assumes that time in instrument checking, calibration tests, sample cleanup, and general maintenance of equipment and premises is fixed. Therefore, it must be allocated to instrument costs regardless of low average numbers of samples tested per day.

Some potential buyers may consider that NIR instrument operation, particularly at lower levels of use, could be performed by an existing employee who is underemployed in his present job. Such a labor division could be most efficient and profitable from an individual firm's point of view. However, for purposes of cost analysis, the alternative use of the underemployed worker's time should be considered, and time allocated to NIR instrument operation must be costed at the assumed labor rate.

Maintenance and repairs.--The cost of maintenance and replacement parts for equipment other than the NIR instrument is estimated at 1 percent of the purchase price.

There is a general lack of documented data on maintenance and repair cost of NIR instruments. The rapid technological change in the instruments and their relatively recent introduction to commercial operation make repair cost analysis difficult. 7/ Furthermore, service and repair charges reported to date may possibly be understated because of competition and introductory sales promotion practices. Instruments are fully warranted for 1 year. Low-cost estimates for maintenance are based on average repair costs of three users at various levels of samples analyzed per day. Maintenance costs are estimated to increase as the number of samples analyzed per day increases. Individual users' repair costs may vary greatly from this estimate. Maintenance contracts are available from NIR instrument manufacturers at an average annual cost of $845 over the assumed 5-year depreciation period. This cost plus the estimated maintenance and repair expense of the remaining equipment is used for the high-cost estimate at all five levels of samples tested per shift. Note, however, that the cost of maintenance and repair for machines under contract, although initially high compared to the low-cost estimates, guarantees that the instrument purchaser will not be surprised with the possibility of unexpectedly high repair costs at some future date within the contract period.

Calibration tests.--Manufacturers and users agree that after initial calibration following purchase, NIR instrument analyses should be monitored through check samples from a service laboratory, by duplicate sample testing using another method of constituent determination, or by daily monitoring of sealed cells of known protein values. 8/ The frequency of testing would, of course, vary with the firm's type of activity, economic implications of testing error, and number of samples analyzed annually. The low-cost estimate for each level of sample rate per shift is based on a minimum need basis and assumes costs covering both calibrations and laboratory fees for check testing of samples. The high-cost estimate assumes additional check sample testing which causes the cost to double as the sample level doubles. Check sampling procedures also are assumed to be correlated to the degree of determination importance. That is, during periods of large incoming or outgoing grain movements, more monitoring might be advisable. Furthermore, grain determinations made for in-house binning purposes probably require fewer check samples than determinations made on shipments to purchasers.

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7/ One NIR instrument manufacturer developed mean-time-between-failure (MTBF) data for an early model of the type of instrument studied herein. A number of instrument failures occurred soon after introduction, but failures steadily decreased until mid-1977, when MTBF for the instrument was about 28 months (8).

8/ A special infrared protein check sample program was recently announced by the American Association of Cereal Chemists to enable laboratories with NIR instruments to maintain an accurate check on NIR instrument calibration. Proposed cost would be $7 weekly for participants (5).

Utilities.--The cost for electrical power, the only utility cost estimated, varies with equipment running time. Manufacturers' instructions for the NIR instrument recommend that the instrument be left on continuously. One reason is the lengthy startup time for instrument stabilization after shutdown. Another reason is that the instrument's electronic system is probably less adversely affected by being on all the time than by repetitive on-off cycles of operation. Grinder requirements for intermittent operation, according to the number of samples ground per day, are included in electrical usage for the low-cost estimate. A more important factor in utility cost determination is equipment location. The high-cost utility estimate reflects costs of operating equipment to control dust and avoid temperature extremes in nonlaboratory instrument locations. The kilowatt hour (kWh) usage of equipment for both low- and high-cost estimates is multiplied by a kWh rate of 3 cents to obtain utility costs.

## ECONOMIC RELATIONSHIPS

Certain economic relationships covering varying output levels of an 8-hour operation and cost ratios between 8-, 16-, and 24-hour operations can be assumed from the foregoing cost data. However, these cost figures do not include other factors which individual firms may wish to consider when evaluating economic feasibility of NIR instrument use. The rapid constituent analyses by NIR instruments is a major economic consideration, and for certain types of operations, such as on-line process monitoring and truck grain unloading, access to grain content information is vitally important. Other factors which may make NIR instruments more attractive than chemical methods are the use of less-skilled operators, fewer safety concerns, disposal ease of materials used in the analysis, and general freedom from the need for environmental regulation.

For a comprehensive cost analysis, estimates should be made on the probable number of samples handled yearly rather than on peak operation per-sample costs. As indicated earlier, most fixed costs remain the same regardless of sample output and use. Certain variable costs--maintenance, repair, and utilities--increase very little as the number of samples analyzed increases, because of the electronic construction of the NIR instrument.

Analysis needs vary, particularly for grain elevators, because receipts and shipments are seasonal, with the heaviest need at harvesttime. It is estimated that adding a second operator to the 80-sample-per-shift operation would double the output to 160 samples per day over a sustained period. (One operator would prepare samples for a second operator running the NIR instrument.) The ability to handle even greater workloads during peak periods would be possible because the per-sample measurement time used here is substantially within instrument capacity. The second operator's wages would be the major additional cost encountered (table 3). However, per-sample costs would decline. The other four levels of operation could, of course, have sample output increased by lengthening an operator's hours per shift or by adding another part-time operator. Increasing sample output will also help to increase operator efficiency at the lower sample levels and, combined with little additional cost increase except operators' wages, will reduce per-sample costs for these operations.

An alternative to adding operators to a particular 8-hour operation as sample analysis needs increase is to increase the number of shifts during a day. This is particularly attractive in conjunction with 24-hour operations such as grain exporting, flour milling, and other grain processes. Cost estimates for 40- and 80-sample multiple shift operations are shown in table 3. Fixed costs, except additional training expenses, remain the same as those in table 2. With the exception of additional operator wages, variable costs increase only slightly over a single-shift operation. Wage rates for second- and third-shift operations increase to $7.25 and $7.50 per hour, respectively.

Table 3--Estimated annual operating costs of NIR instruments for various levels of sample determinations and shifts, 1978 1/

| Cost item | 160 samples per 8-hr. shift 2/ 4/ | | 40 samples per 8-hr. shift 3/ 4/ | | | | 80 samples per 8-hr. shift 3/ 4/ | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Two shifts | | Three shifts | | Two shifts | | Three shifts | |
| | Low | High | Low | High | Low | High | Low | High | Low | High |
| | Dollars | | | | | | | | | |
| Fixed: | | | | | | | | | | |
| Depreciation | 3,292 | 3,544 | 3,292 | 3,544 | 3,292 | 3,544 | 3,292 | 3,544 | 3,292 | 3,544 |
| Interest on investment | 741 | 797 | 741 | 797 | 741 | 797 | 741 | 797 | 741 | 797 |
| Space assessment | 120 | 300 | 120 | 300 | 120 | 300 | 120 | 300 | 120 | 300 |
| Training expense | 189 | 252 | 189 | 252 | 315 | 378 | 189 | 252 | 315 | 378 |
| Taxes and insurance | 75 | 80 | 75 | 80 | 75 | 80 | 75 | 80 | 75 | 80 |
| Total fixed | 4,417 | 4,973 | 4,417 | 4,973 | 4,543 | 5,099 | 4,417 | 4,973 | 4,543 | 5,099 |
| Variable: | | | | | | | | | | |
| Operator wages 5/ | 29,120 | 30,800 | 22,230 | 23,512 | 33,930 | 35,887 | 29,640 | 31,350 | 45,240 | 47,850 |
| Maintenance and repair | 510 | 900 | 425 | 900 | 510 | 950 | 510 | 900 | 680 | 950 |
| Calibration tests | 1,200 | 2,800 | 800 | 2,400 | 1,000 | 2,600 | 1,200 | 2,800 | 1,400 | 3,000 |
| Utilities | 120 | 535 | 105 | 520 | 120 | 535 | 120 | 535 | 130 | 545 |
| Total variable | 30,950 | 35,035 | 23,560 | 27,332 | 35,560 | 39,972 | 31,470 | 35,585 | 47,450 | 52,345 |
| Total | 35,367 | 40,008 | 27,977 | 32,305 | 40,103 | 45,071 | 35,887 | 40,558 | 51,993 | 57,444 |
| Per-sample cost | .85 | .96 | 1.34 | 1.55 | 1.28 | 1.44 | .86 | .97 | .83 | .92 |

1/ Annual capacity based on 260 operating days. One hundred sixty samples per day equal 41,600 samples annually; 40 for two shifts, 20,800; 40 for three shifts, 31,200; 80 for two shifts, 41,600; and 80 for three shifts, 62,400.

2/ Requires two operators.

3/ One operator per shift.

4/ Low figure is minimum cost estimate where the NIR instrument is installed in controlled-environment laboratory. High figure is cost estimate for minimum instrument operating conditions in other locations.

5/ See operator wages section in text for explanation of wage difference in low- and high-cost estimates.

## COST COMPARISONS

Estimated NIR per-sample costs (table 2) are compared with Kansas City-area laboratory charges for Kjeldahl protein and moisture determinations of grain (table 4). Kansas and Missouri sample charges are required by the States' charters to reflect, insofar as possible, actual costs of performing the indicated tests; profit on services is not permitted. This, of course, is not the case for a private concern, which must make a return on investment and cover the risk of business operation. Doty Laboratories, Inc., a private concern located in north Kansas City, therefore, charges a higher fee than the State laboratories. However, Doty Laboratories specializes in more complete testing of a grain or commodity for multiple quality factors than do the State laboratories. Therefore, the total testing charge for users requiring the more complete service would include lower charges for protein and moisture than the testing fees shown in table 4.

Per-sample NIR cost estimates for protein and moisture tests are lower for 20, 40, and 80 samples per 8-hour shift than those at the three Kjeldahl laboratories for which charges are shown. The low-cost estimate for 10 samples per shift is also lower than at all three laboratories. The only level at which estimated NIR costs are above what Doty Laboratories charges is 5 samples per shift.

The NIR instrument models considered in this cost study have the capability to determine other quality measurements, such as starch and oil content of grains and oilseeds and their products. Once the expense of NIR instrument ownership is undertaken, these tests can be done at little additional cost besides operator time. Additionally, more sophisticated NIR instruments are available, at greater cost, which show promise for amino acid analysis of the protein content and for constituent determination of blended products such as flour and animal feeds.

Rapid analysis, smaller space needs, and fewer safety hazards are among the advantages NIR-instrument analysis has over the Kjeldahl method for protein analysis. It appears that NIR instrument use to determine protein and moisture content of grains and their products is economically feasible at all but 5 samples per shift and the high-cost estimate of 10 samples per shift. If economic value were placed on the apparent advantages of NIR instrument analysis, the cost comparison would be even more favorable over the Kjeldahl method.

Table 4--Estimated NIR costs and representative Kansas City-area laboratory charges for protein and moisture determinations of grain, January 1, 1978

| Item | Situation estimate 1/ | Per-sample costs | | |
|---|---|---|---|---|
| | | Protein | Moisture | Total |
| | | | Dollars | |
| NIR estimates: | | | | |
| 5 samples/shift | Low | 2/ | 2/ | 6.44 |
| | High | 2/ | 2/ | 7.91 |
| 10 samples/shift | Low | 2/ | 2/ | 3.25 |
| | High | 2/ | 2/ | 4.01 |
| 20 samples/shift | Low | 2/ | 2/ | 2.35 |
| | High | 2/ | 2/ | 2.80 |
| 40 samples/shift | Low | 2/ | 2/ | 1.54 |
| | High | 2/ | 2/ | 1.83 |
| 80 samples/shift | Low | 2/ | 2/ | .96 |
| | High | 2/ | 2/ | 1.16 |
| Representative Kyeldahl rates: | | | | |
| Doty Laboratories, Inc. | -- | 2.75 | 2.00 | 4.75 |
| Kansas State Grain Inspection Service | -- | 2.50 | 1.00 | 3.50 |
| Missouri State Inspection Bureau | -- | 2.50 | 1.00 | 3.50 |

-- = Not applicable.

1/ Low estimate is minimum cost where the NIR instrument is installed in a controlled-environment laboratory. High estimate is the cost for minimum instrument operating conditions in other locations.

2/ Costs of protein and moisture determinations are combined since moisture content measurement is required in reporting grain protein content on a standard moisture basis.

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# APPENDIX A--Per-Bushel Costs

The costs shown in this study were developed for use by managers and researchers in comparing NIR per-sample costs of protein and moisture content of grain with other methods of determination. The grain industry in the United States presently operates on a bushel basis for most financial accounting and price-reporting activities; prices shown for grain bought and sold, operating margins, futures trading, and volume handled generally are reported on a bushel basis. Per-sample cost can be converted to a bushel basis by grain industry members preferring a bushel-basis analysis.

Several problems arise with the preparation of NIR cost data on a per-bushel basis. Every bushel of grain need not be sampled for analysis, since grain is assembled and traded by lot sample (a lot being a quantity of grain from one area where all grain characteristics are assumed to be the same as defined by a sample taken in a prescribed manner depending on the lot size). Thus, samples to be analyzed represent widely varying quantities of grain.

A second problem is that the variety of vehicles used to transport grain ranges from small trucks and wagons to large semitrailers, railcars, and barges. Additionally, the number and size of storage bins, bin turnovers, and general operating conditions can lead to greatly differing sample numbers needed. There is tremendous variation even in grain elevator operations--from satellite country buying stations active only part of the year to export elevators engaged in 24-hour, year-long operation. Even among storage facilities and processors of similar size and commodities, purchase and sales schedules differ greatly and affect operating characteristics and needs.

Elevator operators should be able to determine from their past crop season and customer records sufficient information to convert NIR instrument operation costs shown in text table 2 to per-bushel costs. For illustrative purposes only, consider the following example as a guide either to developing an approximate per-bushel cost for general use or, by substituting actual costs for those in text table 2, developing a per-bushel cost for a specific firm application.

## Example

The manager of a country elevator in northwest Kansas is interested in the NIR method of determining protein and moisture content of the wheat handled. The intent is to sample each truckload received from farmers and segregate each load insofar as possible in the elevator bins according to a protein range, maintaining this identity through loadout to buyers. Additionally, the manager wishes to provide service for customers who may request testing of some wheat samples from on-farm storage prior to delivery.

### Data

1. The 250,000-bushel elevator handles approximately 500,000 bushels of wheat and sorghum annually.
2. From past records and forecasting it may be assumed that wheat throughput will be 300,000 bushels annually for the next several years.
3. Receipt records indicate incoming wheat from sellers will, for all practical purposes, average 180 bushels per truckload.
4. The elevator consists of eight large bins, approximately 30,000 bushels each, and 12 small working bins.

5. Outgoing transportation to buyers in the past has averaged nearly 75 percent by railcar and 25 percent by truck.

## Procedure

The approximate number of sample analyses handled annually can then be estimated as follows:

1. The 300,000 bushels received from producers divided by 180 bushels per truckload equals 1,667 sample analyses.
2. Bin samples taken during bin filling, turning wheat, and loadout for shipment are estimated to require approximately 225 analyses.
3. Service testing of samples from on-farm wheat and special customer requests are estimated at approximately 100 analyses.
4. The total number of samples estimated to be analyzed would be 1,667 plus 225 plus 100, or nearly 2,000 samples annually. This equals about eight samples per day for 260 operating days.

To estimate approximate per-bushel costs for general use, appendix table 1 has been prepared from text table 2 using total fixed and variable costs at the five sample levels. Appendix table 1 provides a range of annual grain throughput quantities at the five sample levels which can be read directly as per-bushel costs of NIR instrument analyses. For the example, using the 300,000-bushel annual throughput at 10 samples per day, per-bushel costs are 2.8 cents and 3.5 cents for the low- and high-cost estimates, respectively. This is an approximate cost, because the estimated number of samples to be run in the example (2,000) is less than the 2,600 annual capacity of the 10 samples-per-day level.

A manager who has actual cost information available could obtain a comparison of per-bushel costs by dividing the total annual operating cost of using the NIR instrument by the estimated number of bushels handled annually.

## APPENDIX B--Basic Equipment

Basic equipment for NIR instrument analysis of grain constituents is itemized by cost category in appendix table 2. The low-cost estimate described in the methodology section necessitates only equipment listed under the direct and indirect categories. The high-cost estimate includes this equipment plus that listed in the other category.

NIR instrument models shown in appendix table 2 are of similar capacity, and each should perform adequately at the maximum sample level, although each differs in operating characteristics and features. 9/ Dickey-john Corporation has been marketing its models under the InfraAlyzer name in recent years. The model listed was introduced in late 1977 (7). Operating-cost information contained in the text was developed from responses of Neotec and Technicon instrument vendors and grain industry users. Research investigations on the basic principles of NIR instrument operation continue, and new features, characteristics, and techniques are frequently reported by suppliers and researchers (6, 9). Additional NIR models besides those listed herein also are available from the suppliers for users having special needs. Potential buyers should discuss their needs with several suppliers to determine the particular instrument and model suitable for their specific business operation.

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9/ General specifications of NIR instrument models, approved manufacturers, and instrument models are contained in ST NOTICE 19, February 1, 1978, FGIS.

Any of a number of grinders may be used for sample preparation of commodities prior to measurement by the NIR instrument for constituent content. Research is continuing in this area also, as particle size of the sample appears to influence NIR instrument operation. At this time, the grinder most often recommended by NIR instrument suppliers is the UD Corporation model. (The UDY cyclone grinder is the only FGIS-approved grinder at this time for NIR sample preparation. [10/]) The speed of sample grinding and the cleanout feature appear to be important determinants in its selection.

The remaining equipment listed is of a general nature, and numerous suppliers are available. Buyers may wish to select suppliers based on previous purchases, price, service, and location.

The purchase and installation of equipment for NIR analysis of grain constituents does not comprise a large investment ($17,720 for high-cost estimate) for most grain firms. Since most of the operating expense will be for operator wages, a firm should consider equipment installation so as to maximize operator efficiency as well as equipment longevity.

## APPENDIX C--NIR Instrument Depreciation

Although the serviceable life of NIR instruments is difficult to estimate, the instrument is depreciated over 5 years in the development of cost information contained in text table 2. Depreciation expense is by far the largest fixed-cost item, and is very nearly the largest overall cost item for 5 and 10 samples per shift. At these low sample levels, at least three considerations cast doubts on the assumption of a 5-year depreciation schedule. One, lower per-day sample use may affect service life, although recommended procedures are to leave the NIR instrument on continuously. Second, a firm operating the NIR instrument at low-use levels may well be satisfied for many years with a model it has purchased even though newer, more sophisticated models have been introduced. Third, the expected life of NIR instruments is unknown since information on instrument failure and repair cost records are not yet available for long enough periods to provide an economic evaluation. Therefore, appendix table 3 was developed to provide a sensitivity cost analysis of depreciation schedule changes. All other items in the cost schedule of text table 2 are held constant, while depreciation is changed in 1-year increments from 5 to 10 years.

The reader is cautioned that the evaluation may be unfairly biased by the assumption that all other costs remain constant, since maintenance and repair costs may increase because the instrument is operated for longer periods. Also, possible price inflation effects on other costs may become important considerations due to extending the depreciation period. Data shown in appendix table 3 indicate that as the depreciation period is extended, costs for the low sample-per-shift levels greatly decrease. Per-sample costs of the low estimate for 5 samples per shift decrease $0.42 as the depreciation schedule increases from 5 to 6 years, and decrease $1.26 as the depreciation schedule increases to 10 years.

Managers of firms considering investment in an NIR instrument for use at the lower samples-per-shift levels should probably investigate instrument depreciation aspects since estimated costs at lower sample levels are heavily influenced by the depreciation schedule used.

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[10/] General specifications for this grinder are contained in ST NOTICE 12, December 9, 1977, FGIS.

Appendix table 1--Estimated cost of NIR instrument analysis at selected annual throughput rates, 1978

| Samples analyzed 1/ | Total cost 2/ |  | Cost per bushel 2/ |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Low | High | Low | High | Low | High | Low | High | Low | High |
|  |  |  | Annual throughput (1,000 bushels) |  |  |  |  |  |  |  |
|  |  |  | 50 |  | 100 |  | 150 |  | 200 |  |
|  | ---Dollars--- |  | Cents |  |  |  |  |  |  |  |
| 5 samples/shift (1,300/year) | 8,379 | 10,285 | 16.8 | 20.6 | 8.4 | 10.3 | 5.6 | 6.8 | 4.2 | 5.1 |
|  |  |  | Annual throughput (1,000 bushels) |  |  |  |  |  |  |  |
|  |  |  | 200 |  | 300 |  | 400 |  | 500 |  |
|  | ---Dollars--- |  | Cents |  |  |  |  |  |  |  |
| 10 samples/shift (2,600/year) | 8,451 | 10,437 | 4.2 | 5.2 | 2.8 | 3.5 | 2.1 | 2.6 | 1.7 | 2.1 |
|  |  |  | Annual throughput (1,000 bushels) |  |  |  |  |  |  |  |
|  |  |  | 500 |  | 650 |  | 800 |  | 950 |  |
|  | ---Dollars--- |  | Cents |  |  |  |  |  |  |  |
| 20 samples/shift (5,200 /year) | 12,224 | 14,590 | 2.4 | 2.9 | 1.9 | 2.2 | 1.5 | 1.8 | 1.3 | 1.5 |
|  |  |  | Annual throughput (1,000 bushels) |  |  |  |  |  |  |  |
|  |  |  | 1,000 |  | 1,300 |  | 1,600 |  | 1,900 |  |
|  | ---Dollars--- |  | Cents |  |  |  |  |  |  |  |
| 40 samples/shift (10,400/year) | 16,059 | 19,045 | 1.6 | 1.9 | 1.2 | 1.5 | 1.0 | 1.2 | .8 | 1.0 |
|  |  |  | Annual throughput (1,000 bushels) |  |  |  |  |  |  |  |
|  |  |  | 2,000 |  | 3,000 |  | 4,000 |  | 5,000 |  |
|  | ---Dollars--- |  | Cents |  |  |  |  |  |  |  |
| 80 samples/shift (20,800/year) | 19,959 | 24,105 | 1.0 | 1.2 | .7 | .8 | .5 | .6 | .4 | .5 |

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1/ Average number of samples analyzed per 8-hour shift; annual capacity based on 260 operating days.

2/ Low figure is minimum cost estimate where NIR instrument is installed in controlled-environment laboratory. High figure is cost estimate for minimum sufficient instrument operating conditions in other locations.

Appendix table 2--Basic equipment specifications, available suppliers, and costs

| Cost item | Units required | Model number | Size or capacity | Electricity | Supplier | Cost 1/ | Salient features 2/ |
|---|---|---|---|---|---|---|---|
| | | | | Watts | | Dollars | |
| Direct: | | | | | | | |
| NIR instrument | 1 | GAC III | 15 sec/ sample | 460 | Dickey-john Corporation Auburn, Ill. | 14,750 | Includes printer. Wave-length capacity of 10 filters, 48 constituents |
| | | GQA31EL | 10 sec/ sample | 350 | Neotec Instruments, Inc. Silver Spring, Md. | 14,950 | Allows measurement of 4 constituents at once, includes 3 calibration cards--maximum 12 constituents. |
| | | Infra-Alyzer 2.5A | 15 sec/ sample | 500 | Technicon Industrial Systems, Tarrytown, N.Y. | 13,800 | Allows measurement of 3 constituents at once, additional calibrations available at $600 for 3 channels--maximum 9 cons. |
| Grinder | 1 | UDY MS Cyclone sample mill | 1 gm/sec | 885 | UD Corporation Boulder, Colo. | 745 | 12,600 RPM, belt driven. No clean out required between samples |
| Indirect: | | | | | | | |
| Instrument bench | 1 | | 5' x 30" | | Local supplier | 50 | 2 large storage drawers |
| Work table | 1 | | 4' x 30" | | Local supplier | 100 | 1 small drawer |
| Chair | 2 | | standard | | Local supplier | 50 | swivel, without arms |
| Other: | | | | | | | |
| Air conditioner | 1 | | 8,000 Btu | | Local supplier | 300 | |
| Room heater | 1 | | 10,500 Btu | | Local supplier | 100 | |
| Hood and exhaust fan | 1 | | 30" x 24" | | Local supplier | 250 | 300 cfm exhaust |

1/ As of January 1, 1978. Does not include freight charges for NIR instrument or grinder. Local purchase price estimates for remaining items.

2/ NIR instrument suppliers have available lease agreements, deferred payment contracts, and per-sample rental contracts for customers desiring other than immediate-terms instrument purchase.

Appendix table 3--Estimated annual cost of NIR unit

| Cost item | Unit | Equipment depreciation 1/ | | | | | |
|---|---|---|---|---|---|---|---|
| | | 5 years | | 6 years | | 7 years | |
| | | Low | High | Low | High | Low | High |
| Depreciation | Dol. | 3,292 | 3,544 | 2,743 | 2,953 | 2,351 | 2,531 |
| Fixed-cost percentage | Pct. | 76 | 72 | 72 | 68 | 69 | 65 |
| Total cost: | | | | | | | |
| 5 samples/shift | Dol. | 8,379 | 10,285 | 7,830 | 9,694 | 7,438 | 9,272 |
| 10 samples/shift | do. | 8,451 | 10,437 | 7,902 | 9,846 | 7,510 | 9,424 |
| 20 samples/shift | do. | 12,224 | 14,590 | 11,675 | 13,999 | 11,283 | 13,577 |
| 40 samples/shift | do. | 16,059 | 19,045 | 15,510 | 18,454 | 15,118 | 18,032 |
| 80 samples/shift | do. | 19,959 | 24,105 | 19,410 | 23,514 | 19,018 | 23,092 |
| Per-sample cost: 2/ | | | | | | | |
| 5 samples/shift | do. | 6.44 | 7.91 | 6.02 | 7.46 | 5.72 | 7.13 |
| 10 samples/shift | do. | 3.25 | 4.01 | 3.04 | 3.79 | 2.89 | 3.62 |
| 20 samples/shift | do. | 2.35 | 2.80 | 2.24 | 2.69 | 2.17 | 2.61 |
| 40 samples/shift | do. | 1.54 | 1.83 | 1.49 | 1.77 | 1.45 | 1.73 |
| 80 samples/shift | do. | .96 | 1.16 | .93 | 1.13 | .91 | 1.11 |

| Cost item | Unit | Equipment depreciation 1/ | | | | | |
|---|---|---|---|---|---|---|---|
| | | 8 years | | 9 years | | 10 years | |
| | | Low | High | Low | High | Low | High |
| Depreciation | Dol. | 2,058 | 2,215 | 1,829 | 1,969 | 1,646 | 1,772 |
| Fixed-cost percentage | Pct. | 66 | 62 | 62 | 59 | 61 | 56 |
| Total cost: | | | | | | | |
| 5 samples/shift | Dol. | 7,145 | 8,956 | 6,916 | 8,710 | 6,733 | 8,513 |
| 10 samples/shift | do. | 7,217 | 9,108 | 6,988 | 8,862 | 6,805 | 8,665 |
| 20 samples/shift | do. | 10,990 | 13,261 | 10,761 | 13,015 | 10,578 | 12,818 |
| 40 samples/shift | do. | 14,825 | 17,716 | 14,596 | 17,470 | 14,413 | 17,273 |
| 80 samples/shift | do. | 18,725 | 22,776 | 18,496 | 22,530 | 18,313 | 22,333 |
| Per-sample cost: 2/ | | | | | | | |
| 5 samples/shift | do. | 5.50 | 6.89 | 5.32 | 6.70 | 5.18 | 6.55 |
| 10 samples/shift | do. | 2.78 | 3.50 | 2.69 | 3.41 | 2.62 | 3.33 |
| 20 samples/shift | do. | 2.11 | 2.55 | 2.07 | 2.50 | 2.03 | 2.46 |
| 40 samples/shift | do. | 1.42 | 1.70 | 1.40 | 1.68 | 1.38 | 1.66 |
| 80 samples/shift | do. | .90 | 1.10 | .89 | 1.08 | .88 | 1.07 |

1/ Low figure is minimum cost estimate where NIR instrument is installed in a controlled-environment laboratory. High figure is cost estimate for minimum sufficient instrument operating conditions in other locations. 2/ Annual capacity based on 260 operating days. Five samples per day equal 1,300 annually; 10 samples, 2,600; 20 samples, 5,200; 40 samples, 10,400; and 80 samples; 20,800.

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